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Publication date:
2012

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Citation (APA):
Babicheva, V., Kulkova, I., Malureanu, R., Yvind, K., & Lavrinenko, A. (2012). *Plasmonic modulator based on finite-thickness metal-semiconductormetal waveguide with gain core*. Paper presented at Northern Optics 2012, Snekkersten, Denmark.

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Plasmonic modulator based on finite-thickness metal-semiconductor-metal waveguide with gain core

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Ultra-compact and ultra-fast modulators are among the main requirements for modern photonic integrated circuits. Their potential applications range from direct laser modulation to on-chip optical routing and computation. A surface plasmon polariton modulator supplemented with a loss-compensation mechanism provides such possibilities. The surface waves at a metal–dielectric interface – the surface plasmon polaritons (SPPs) – are strongly bounded to it. This tight binding between the SPPs and the interface allows the control of light at nanoscale. Plasmonic devices are promising for optoelectronic integrated circuits because of small sizes and high operation speed.

Different types of plasmonic modulators have been studied during last several years [1-4]. It has been shown that several designs outperform more conventional silicon-based modulators [3]. Furthermore, a structure where the active core is sandwiched between two metal claddings is very promising as it allows high field confinement between the metal plates. The metal plates can, in the same time, serve as the electrodes for electrical pumping of the gain material.

We focus on plasmonic modulators with gain core to be implemented as active nanodevices (Fig. 1). In particular, we theoretically analyze metal-semiconductor-metal (MSM) waveguides with the InGaAsP-based active material layers. A MSM waveguide enables a high effective index of the propagating mode and, therefore, effective modulation. The modulation is achieved by changing the gain of the core that results in different transmittance through the waveguide. Bulk semiconductor, quantum wells and quantum dots arranged in either horizontal or vertical layout, are considered as the core of the MSM waveguide. The designs address also practical aspects like n- and p-doped layers and barriers and feasible levels of gain.

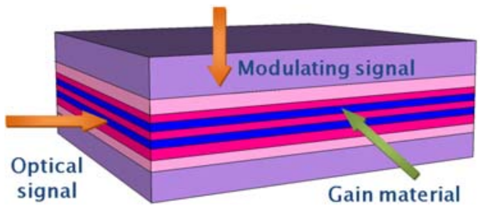

Fig. 1. Plasmonic modulator with gain core.

We optimize the structure by considering thin (up to 20 nm) metal layers (Fig. 2). The implementation of such layers as waveguide claddings allows achieving several times higher effective indices than in the case of a waveguide with thick (>50 nm) metal layers. In turn, the high effective index leads to enhanced modulation speed. We show that the MSM waveguide with electrical current control of the gain incorporates compactness and deep modulation along with a reasonable level of transmittance.

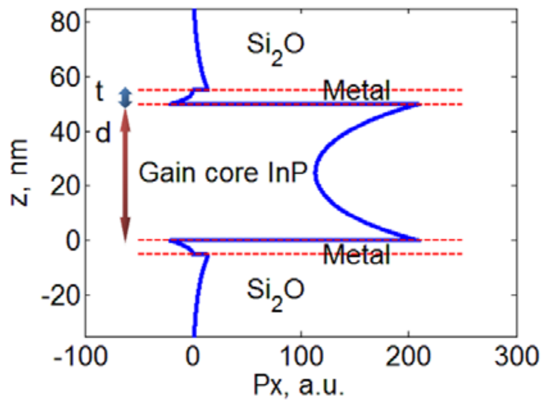

Fig. 2. Poynting vector distribution in the finite-thickness MSM waveguide.

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